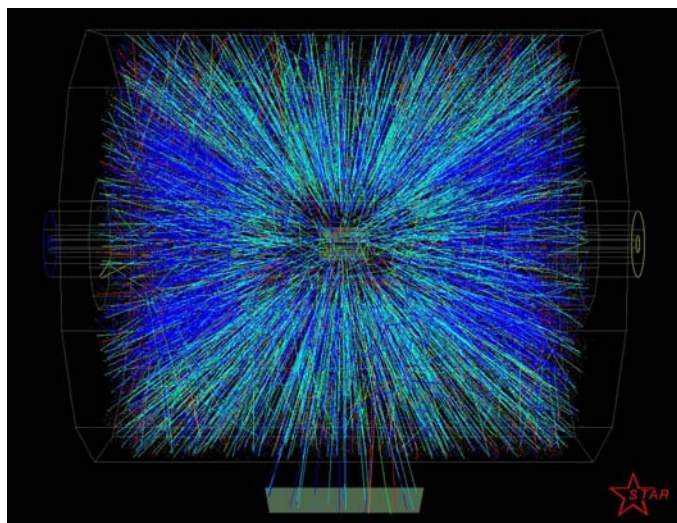


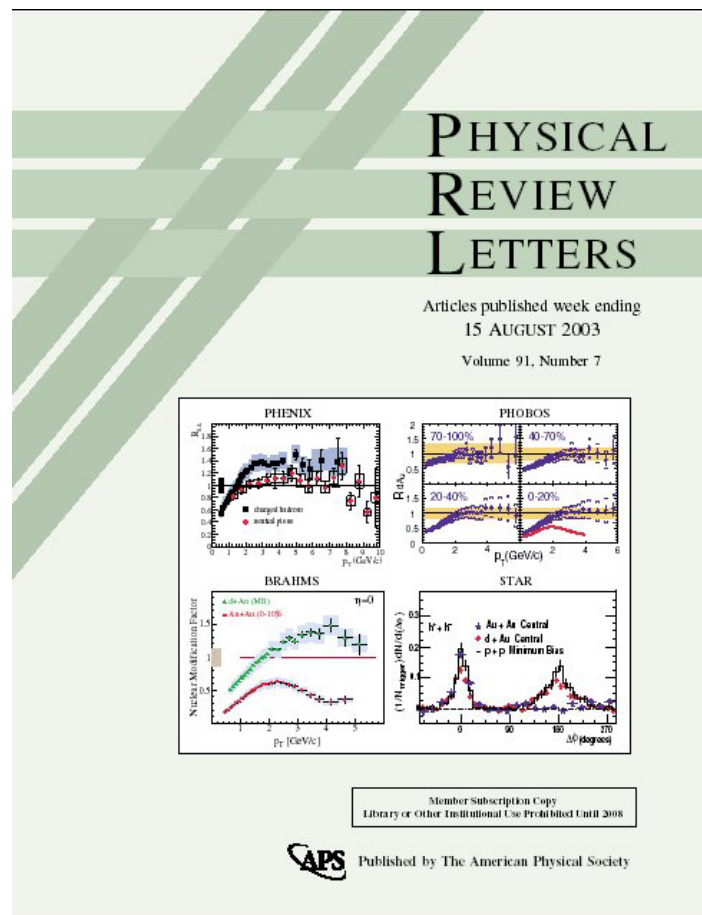
RHIC Physics Experiments Highlights and Plans

RHIC BeamEx Workshop
October 15, 2003

T. Ludlam

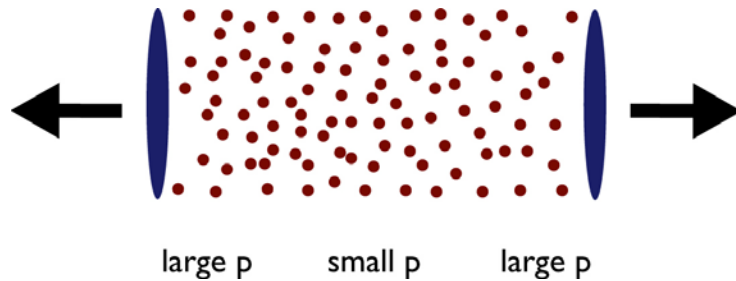


Brookhaven Science Associates
U.S. Department of Energy

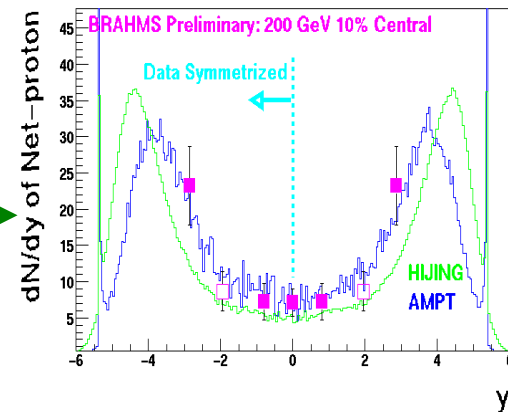
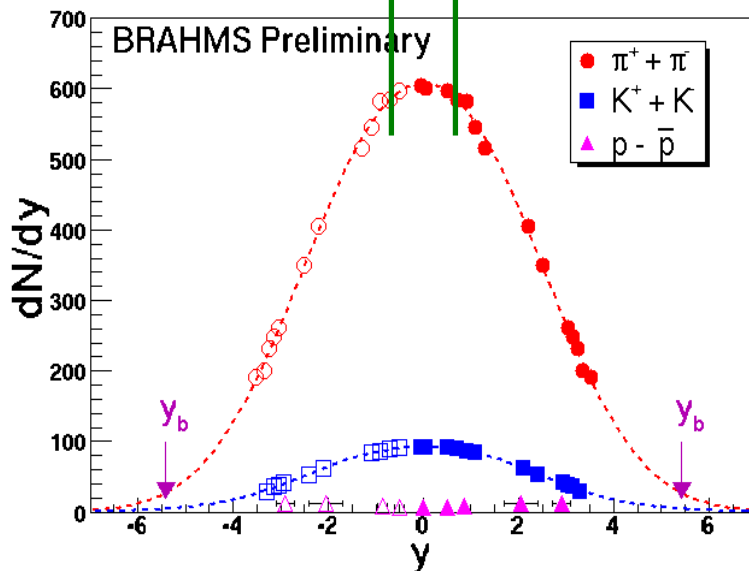


BROOKHAVEN
NATIONAL LABORATORY

Anatomy of a [central] RHIC collision



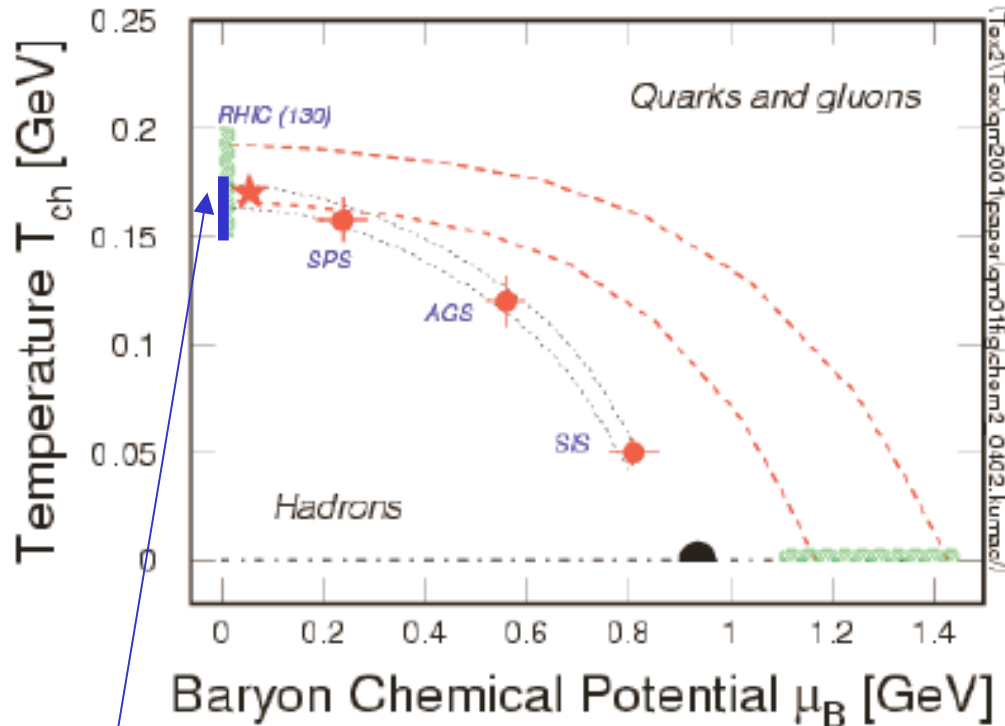
Initial Energy Density:
 $\varepsilon_0 = 5 - 30 \text{ GeV/fm}^3$



Near-zero baryon density at mid-rapidity:

Net baryons ~1% of particle density.
 3/4 of observed protons are from pair prod.

Thermodynamics of strong matter



- It's hot enough...
- It's dense enough...
- Is it "matter" (thermal)?
- Is it "quark matter" (partons in thermal equilibrium)?

Lattice QCD calculations: $T_{critical} \sim 150 - 180$ MeV

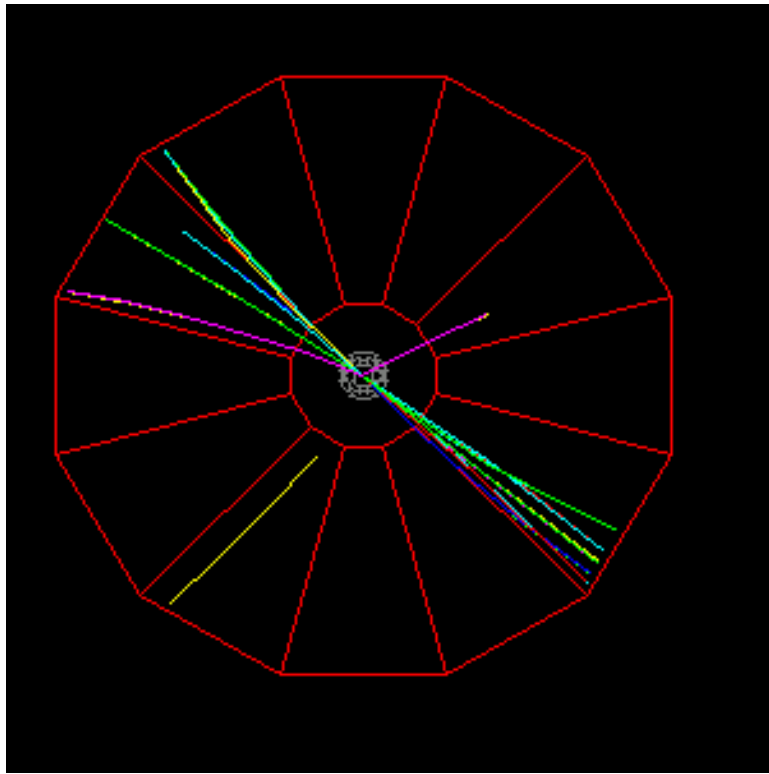
See F. Karsch, Nucl. Phys. A698, 199c

Hard Scattering at RHIC

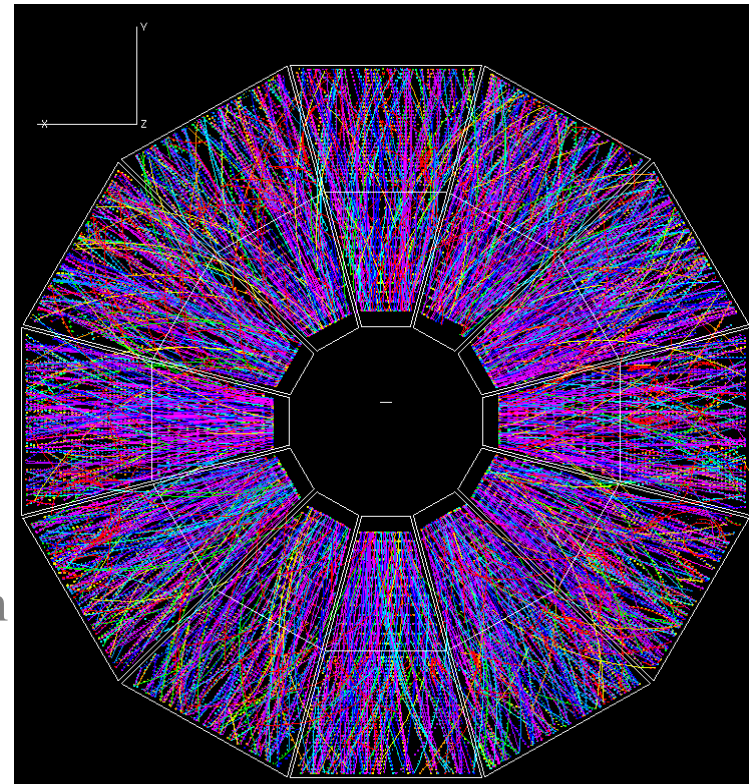
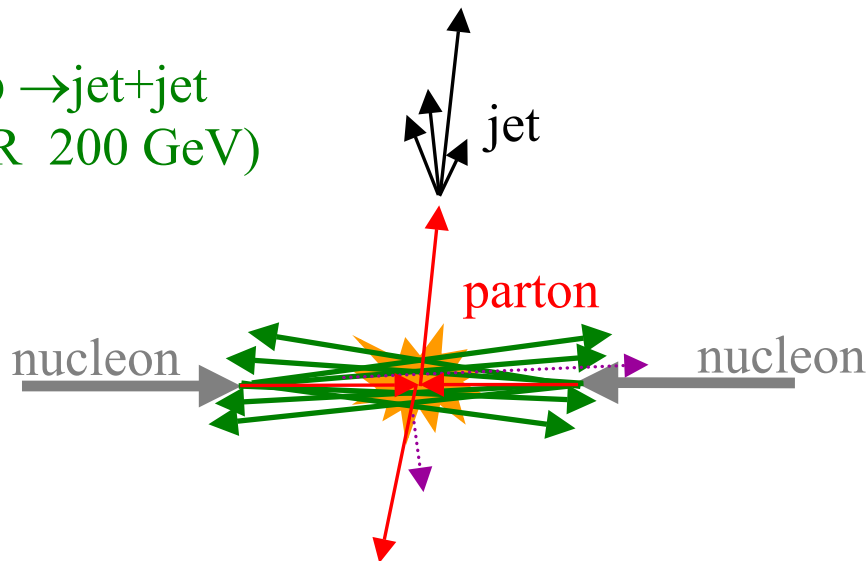
cross sections are high!

$\text{Au}+\text{Au} \rightarrow ???$

(STAR 200 GeV/nucleon)

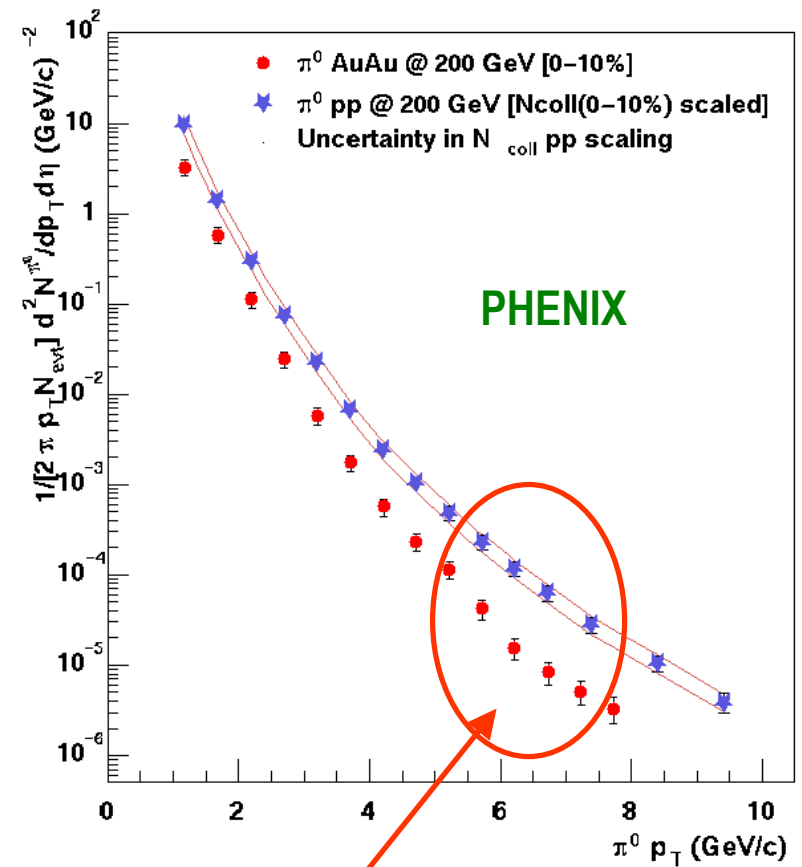
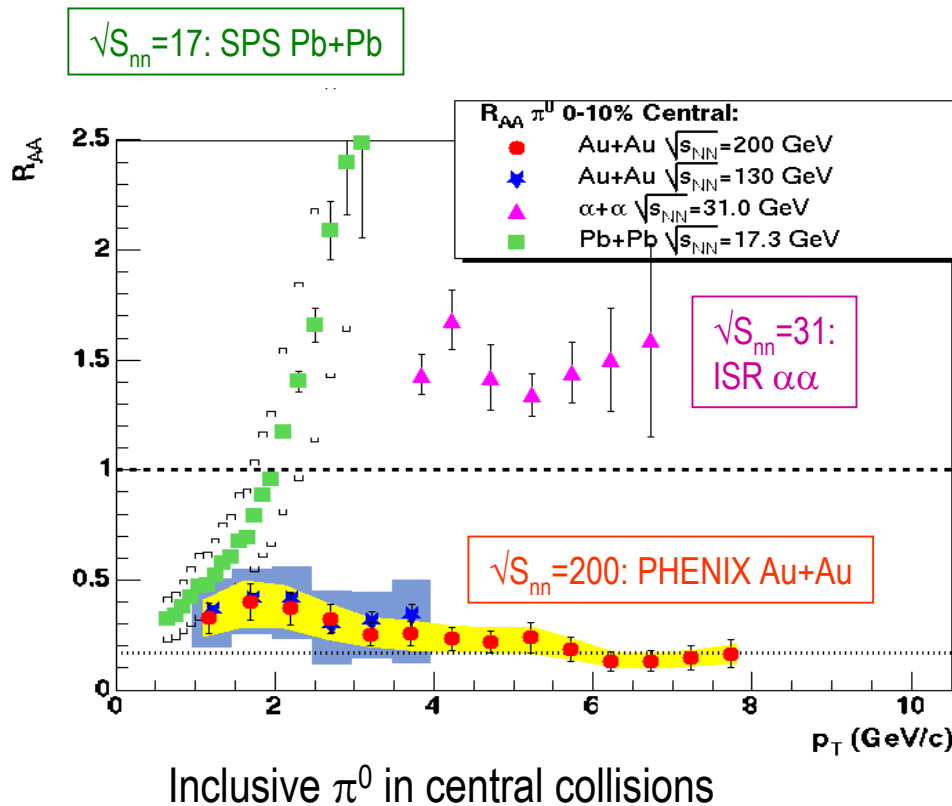


$p+p \rightarrow \text{jet}+\text{jet}$
(STAR 200 GeV)



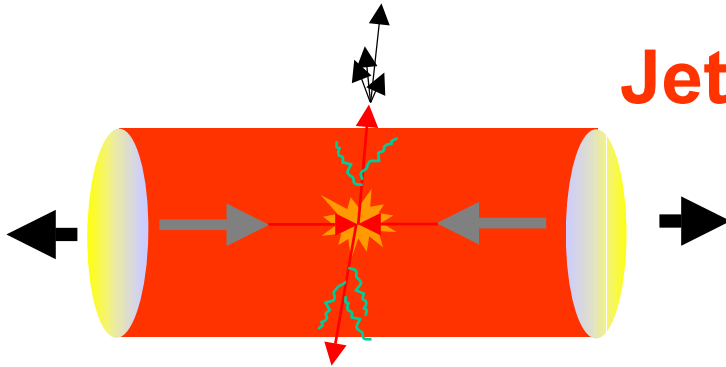
High P_t Data

Well measured, as function of centrality, to $p_t > 10$ GeV/c.
Calibration data from p – p collisions in the same detectors.

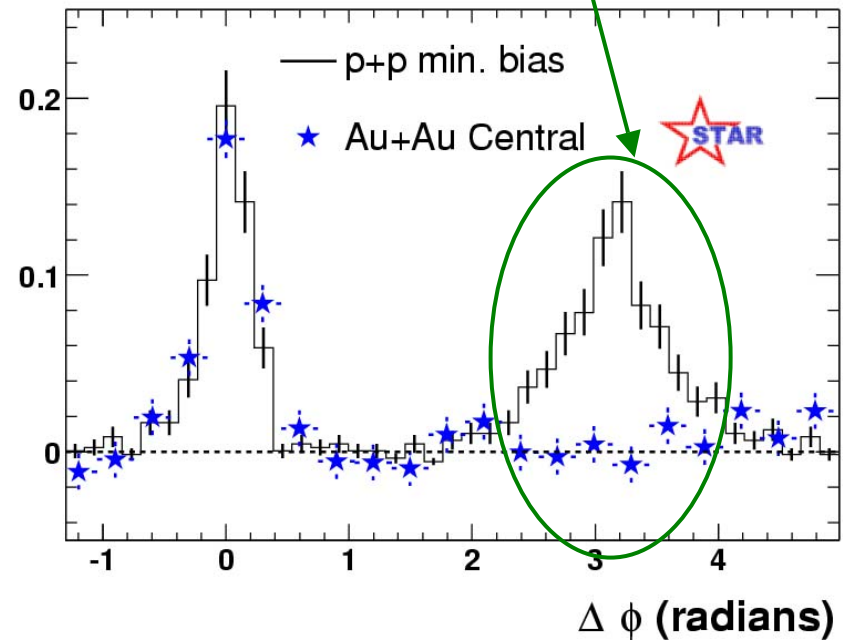
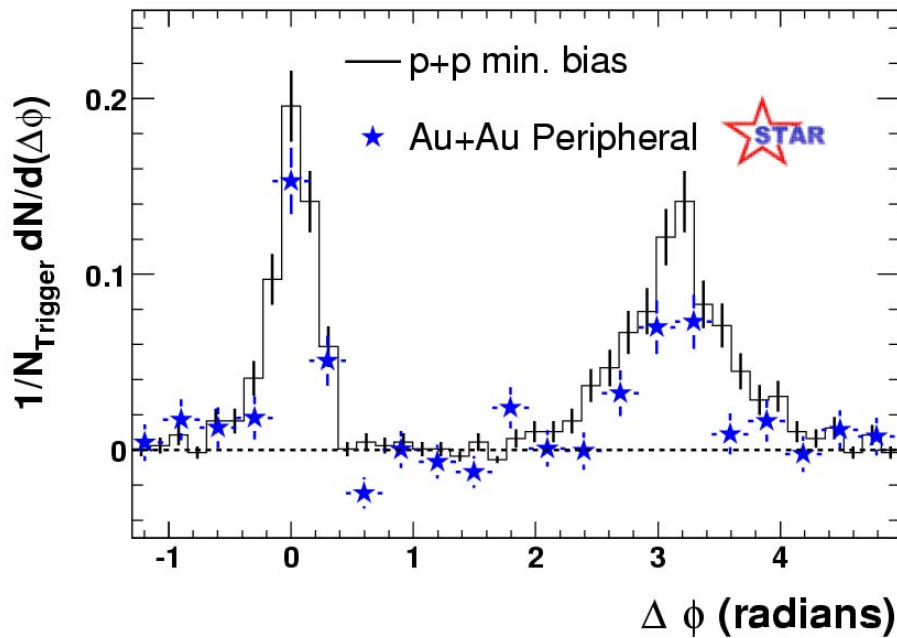


Clear suppression in central Au-Au relative to p – p at large p_t

Jet Quenching?

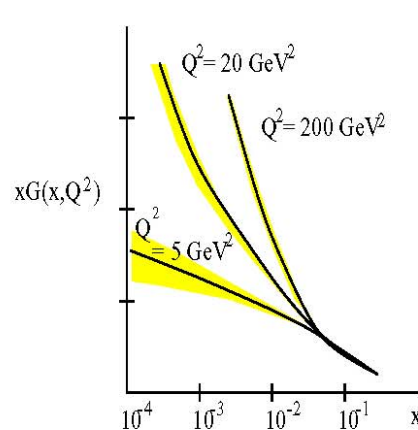


Strong suppression of
back-to-back correlations
in central Au+Au



STAR data: $\sqrt{s_{nn}} = 200$ GeV

Gluon Saturation and Color Glass Condensate



Gribov, Levin, Ryskin;
Mueller, Qiu
McLerran, Venugopalan

Gluon phase space
density per unit
area:

$$\rho = \frac{1}{\pi R^2} \frac{dN}{dp_T^2}$$

until

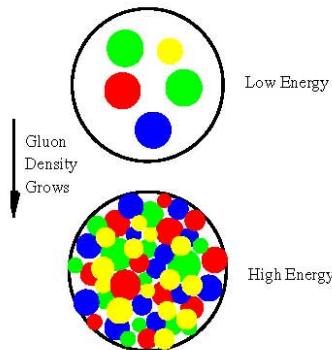
$$\rho \sim 1/\alpha_{strong}$$

$$Q_{sat}^2 \sim \int d^2k_T \rho$$

$$Q_{sat} \gg \Lambda_{QCD}$$

implies

$$\alpha_{strong} \ll 1$$



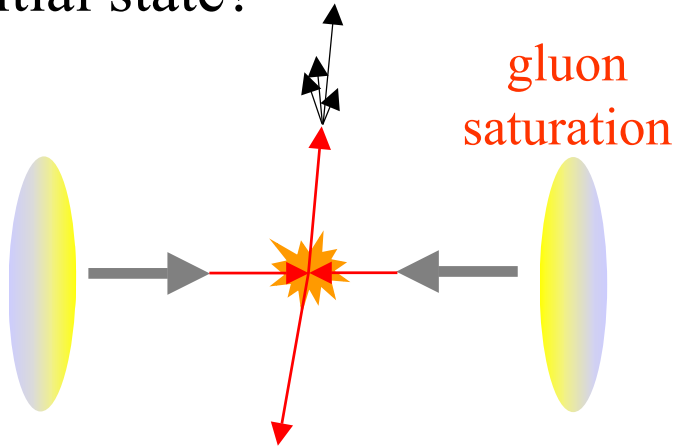
A new, emerging view of AA physics:

Not everything happens in the final state... "A lot of action is going on even before the nuclei collide"
(Kharzeev, McLerran & Co.)

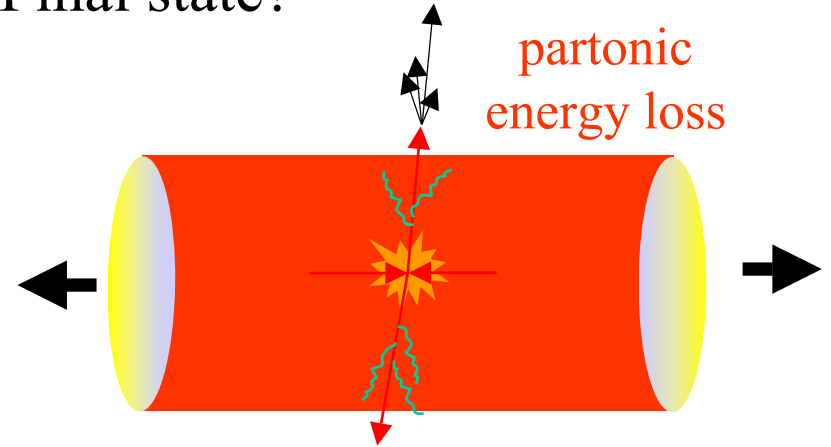
In this picture ... Jets are not quenched, but are *a priori* made in fewer numbers due to saturation of initial-state gluon density.

Is suppression an initial or final state effect?

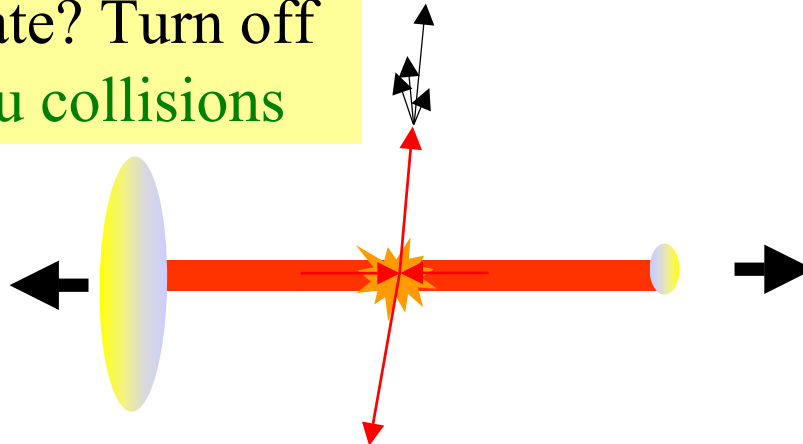
Initial state?



Final state?

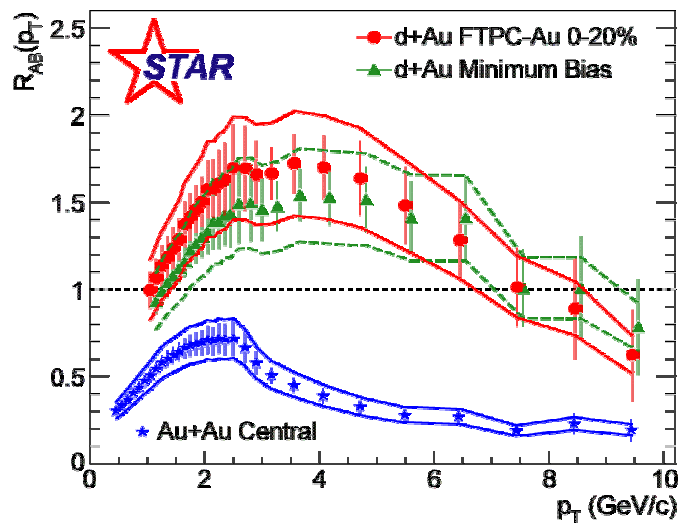


How to discriminate? Turn off final state \Rightarrow d+Au collisions

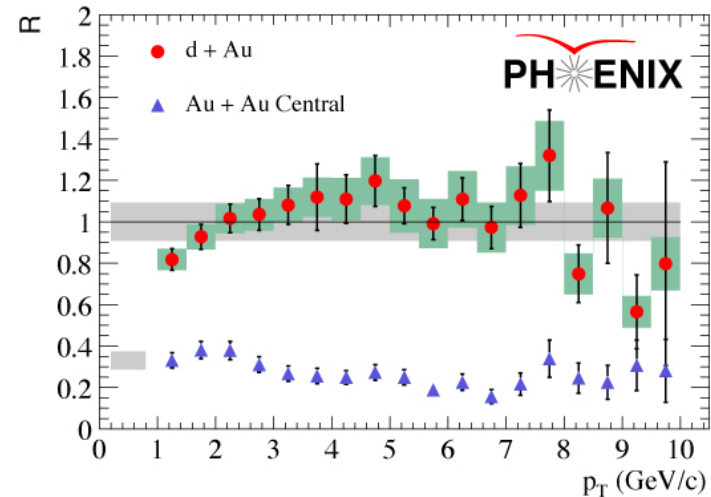


The verdict is in...

Deuteron-gold data at $\sqrt{s_{nn}} = 200$ GeV recorded Jan – Mar 2003



STAR charged hadrons

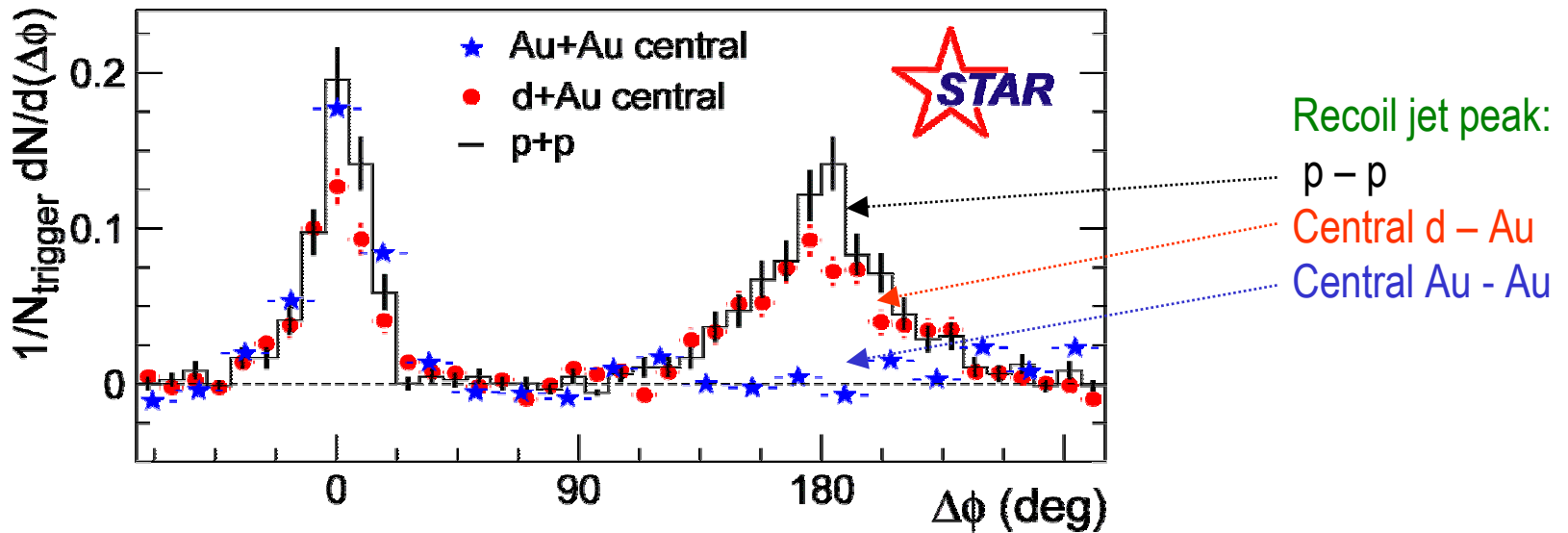


PHENIX pi-zeros

[Phys. Rev. Lett. 91, Aug. 2003](#)

nucl-ex/0306021 (PHENIX); nucl-ex/0306025 (PHOBOS);

nucl-ex/0307003 (BRAHMS); nucl-ex/0307007 (STAR)



June 18, 2003 press release...

The data indicate a hot, dense medium of final state particles that is characterized by strong collective interactions at very high energy densities.

Are we seeing QGP at RHIC?

First question: do we have “Matter” at high energy density?

- Strong collective interaction; local kinetic equilibrium...
Large volume compared with mean free path? } **Yes**

Is it quarks and gluons?

- Temperature and energy density well above critical values? **Yes**
- Strong collective interaction at very early times? **Heavy quark flow?**
- Color screening in dense phase? **J/ψ; open charm, beauty**
- Opaque to jets? **Yes**

Is there a phase transition?

- Chiral symmetry restored (shifted ρ mass)? **Low-mass e-pairs**
- Lattice predictions for the equation of state (latent heat)?
Direct photons; energy scan; species scan

There is a lot more to learn, but at this point it appears that the answer is **Yes**.

Further progress requires several large data samples

Full-energy Au-Au: hundreds of μb^{-1}

- J/ψ , open charm, upsilon
- Identified particles at $p_T > 5 \text{ GeV}/c$
- v_2 (flow) at $p_T \approx 10 \text{ GeV}/c$

Energy scan

- $\sqrt{s} = 62.4 \text{ GeV}$ ISR p+p comparison data

Species scan (system size)

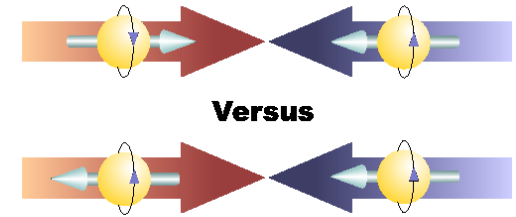
Jet quenching effects $\sim A^{2/3}$

Cu: Au ≈ 0.5

Si: Au ≈ 0.3

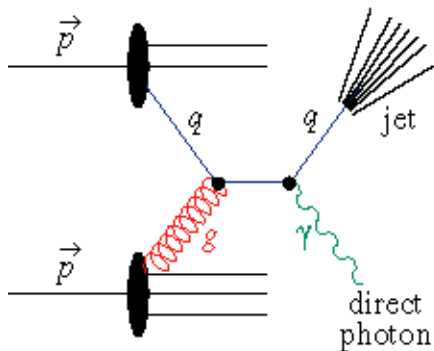
Can we “turn off” the effects we attribute to hot, dense matter?

Spin at RHIC



High Energy collisions of polarized protons:

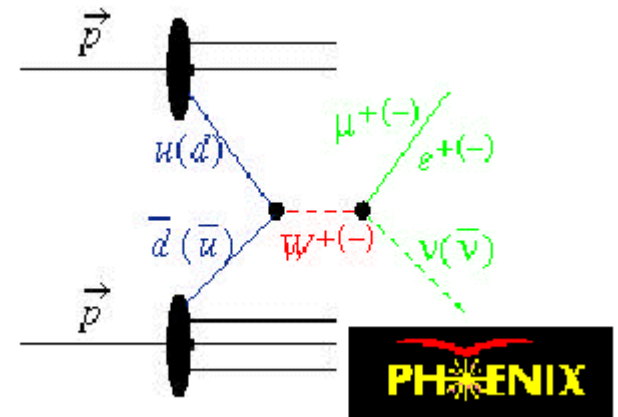
- Measure the gluon contribution to the spin of the nucleon.
- Flavor decomposition of the proton's spin.



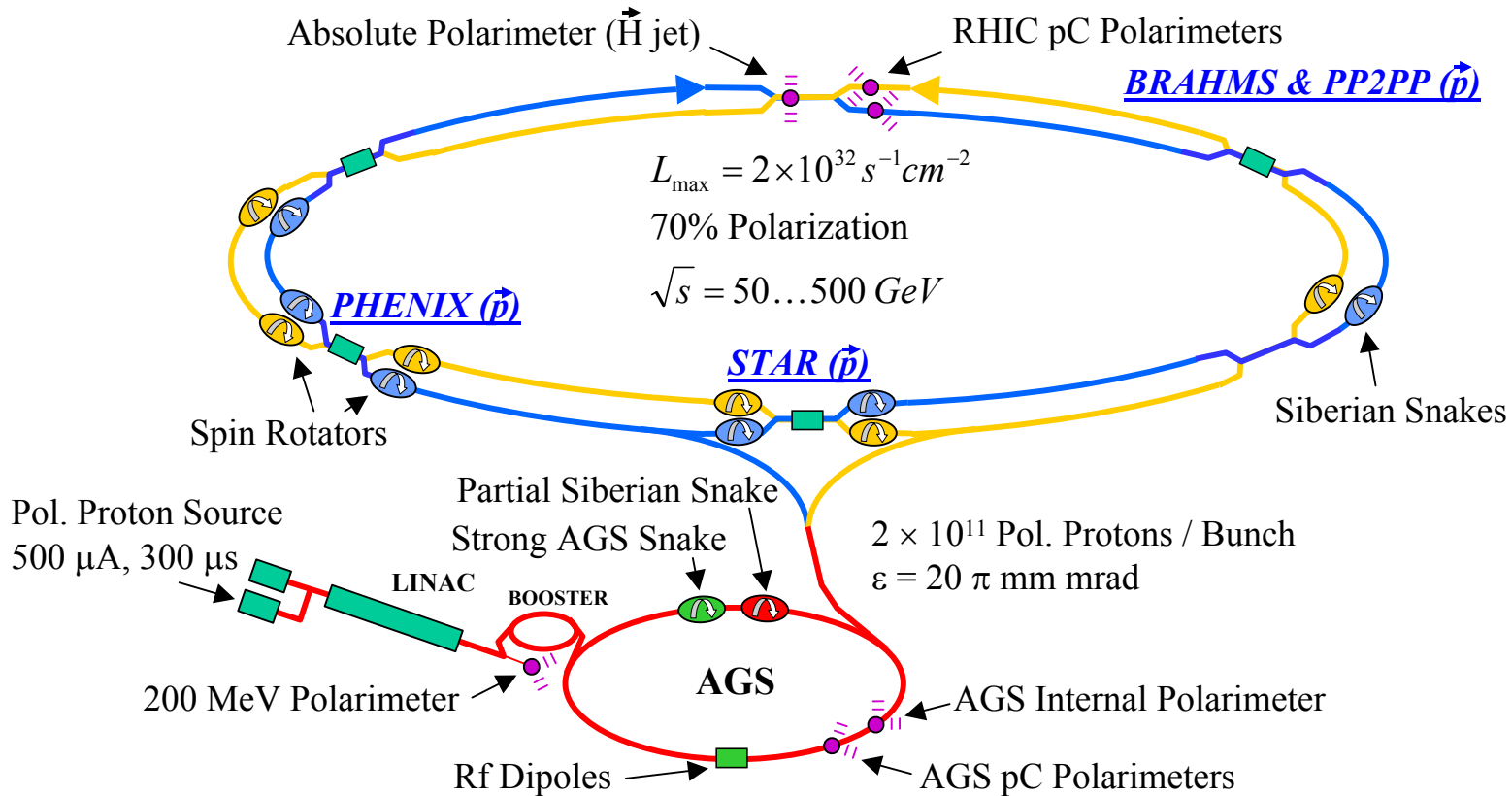
Quark-Gluon Compton scattering

$$\vec{p} + \vec{p} \rightarrow \gamma (+ \text{jet}) + X$$

STAR



Polarized Proton Collisions in RHIC



- First colliding beams of polarized protons achieved in 2002
- First data with longitudinally polarized beams (spin rotators) in 2003
- Full Spin capability for machine and detectors will ramp up through 2005

The Big Challenge

The “Baseline” spin physics goals require data samples of $\sim 100 \text{ pb}^{-1}$, with polarization $>50\%$.

The p+p luminosity achieved in Run 3 was $0.6 \text{ pb}^{-1}/\text{week}$.

Thus...

Heavy Ion Program requires large data sets with many beam settings, hence lots of setup time.

Spin Program requires long, sustained runs to develop machine performance.

A “constant effort” operations plan over the next 5 – 10 years, with ~ 27 cryo weeks/year, doesn’t allow us to do both.

Beam Use Proposals: 27 wks/yr

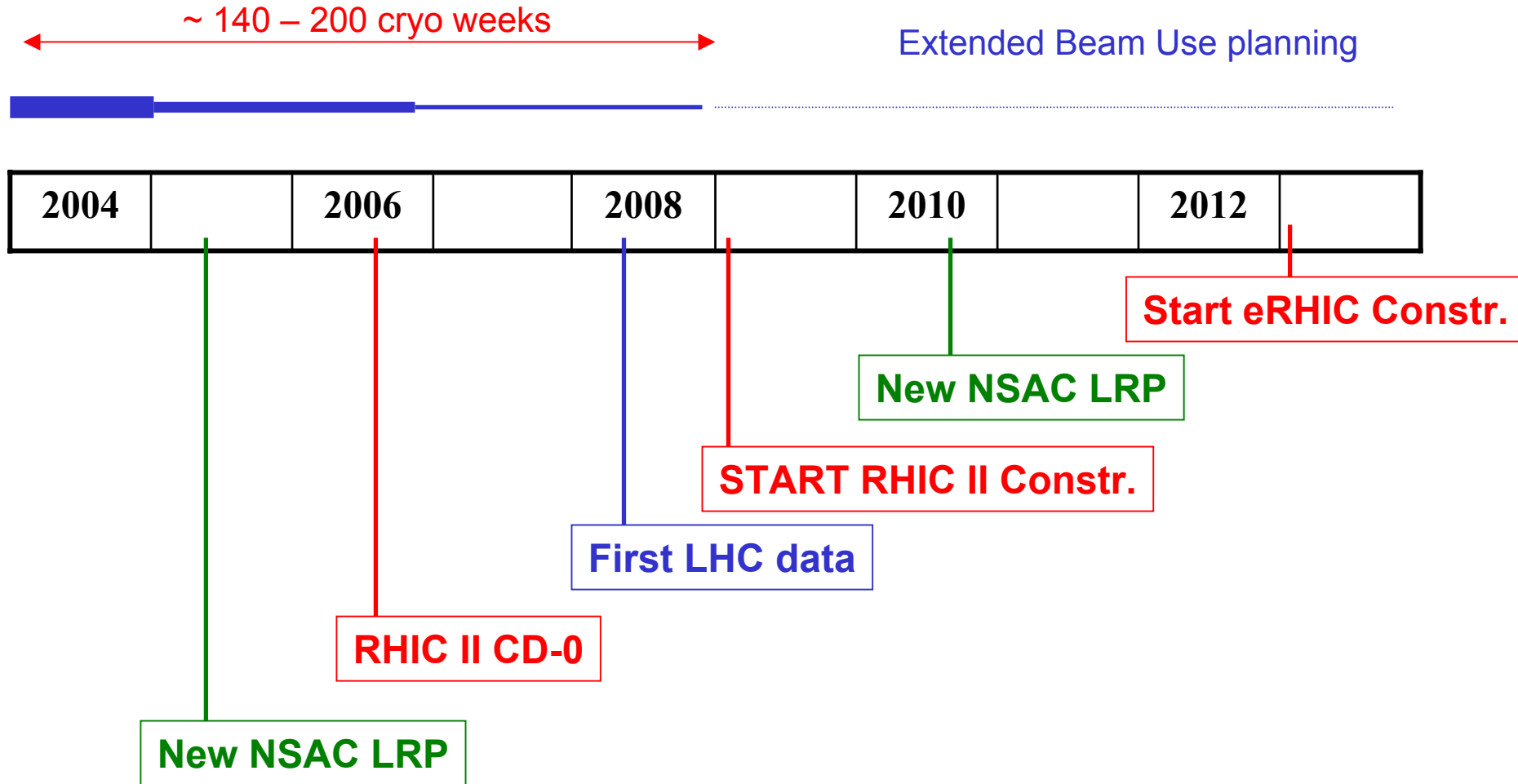
RHIC 5 Year Planning – Constant Effort Summary 9/15/03 Running Modes

Fiscal Year	2003	2004	2005	2006	2007	2008
PHENIX	d+Au 200 GeV 16 weeks, 2.7 nb-1 p+p 200 GeV 10 weeks, 0.35 pb-1, 27%	Au+Au 200 GeV 5+14 weeks, 123 ub-1 p+p 200 GeV 5+0 weeks beam development	Si+Si 200 GeV 5+9 weeks, 2.2 nb-1 p+p 200 GeV 5+5 weeks, 1.2 pb-1 50%	Au+Au 62.4 GeV 5+19 weeks, 45 ub-1	p+p 200 GeV 5+19 weeks, 62 pb-1 60%	Au+Au 200 GeV 5+19 weeks, 840 ub-1
STAR	d + Au 38.2M 5+11 weeks ; pp 10 weeks : T 0.39 pb ⁻¹ L 0.37 pb ⁻¹	AuAu 5+14 pp 200 GeV 5 wk	Au or Fe 5+9 Energy scan pp 200 GeV 5+5 wk	d + Au 5+9 pp 200 GeV 5+5 wk	AuAu 5+5 pp 200 GeV 5+9wk	AuAu 5+10 pp 500 GeV 5+5wk
PHOBOS		AuAu@200 5+10(18) FeFe@200 5+4(6)	pp@200 5+7(12) AuAu@63 5+7(12)	pp@500 8+4 Add. Species Add. Energy	Possible additional running to make up shortfalls	-----
BRAHMS		Au-Au 200 5+19	Fe-Fe 200 5+5 pp 200 5+4	Au-Au 63 2+6 Au-Au 200 2+5 pp 200 5+4	-----	-----

Alternative running scenarios: “constant effort”

	Weeks per run		Alternative scenarios			
	Cryo wks	Phys wks: 2 modes/run	Cryo wks	Phys wks: 2 modes/run	Phys wks: 3 modes/long run	Phys wks: 4 modes/long run
2004	27	14	27	14	14	14
2005	27	14	54	41	36	31
2006	27	14				
2007	27	14	54	41	36	31
2008	27	14				
Total phys wks		70		96	86	76

Planning for the longer term



RHIC Planning Group: Goal/Charge

Map the broad scientific priorities of the RHIC community onto a realistic schedule for facility operations and upgrades.

Starting points...

- Beam Use Requests and Decadal Plans
- PAC and Detector Adv. Comm. Recommendations
- Requirements for machine operation and evolution
- DOE Budget Guidance
- NSAC Long Range Planning process

5 Year Plan

10 Year Outlook



• Optimize ops scenarios

• Re-establish RHIC II

• Update plans for eRHIC



Input to BNL plan for DOE Review

RHIC Planning Group

Convenors: T. Kirk, T. Ludlam

PHENIX G. Bunce A. Drees E. O'Brien W. Zajc	STAR W. Christie T. Hallman R. Majka S. Vigdor	PHOBOS M. Baker G. Roland P. Steinberg	BRAHMS F. Videbaek J.H. Lee
Accelerator J. Alessi I. Ben Zvi W. Fischer P. Pile V. Ptitsyn T. Roser	Theory D. Kharzeev W. Vogelsang	Computing B. Gibbard T. Throwe	PAC/DAC Invited R. Betts P. Jacobs S.-Y. Lee J. Nagle

Ex Officio: S. Aronson, D. Lowenstein, P. Paul

Some important near-term dates *vis a vis RHIC Planning*

- | | |
|----------|---|
| Oct. 31 | “Decadal plans” due from experiments |
| Nov. 22 | Detector advisory committee meeting <ul style="list-style-type: none">• recommendations on STAR TOF and PHENIX Si Tracker proposals• update detector R&D plans |
| Dec. 3-4 | Open Meeting on RHIC Planning |
| Dec. 5-6 | PAC meeting <ul style="list-style-type: none">• recommendations on Decadal Plans |